Analysis of Total Mercury Concentrations in Fish Samples from Jordan Creek and Non-Jordan Creek Sites

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Introduction

In the summer of 2005, Idaho DEQ initiated a fish tissue, stream sediment, and water column monitoring effort to document current mercury levels in the Jordan Creek Watershed (Ingham 2005). Fish collection and the tissue analysis had three main objectives; 1) assist in the evaluation of fish mercury levels compared to the newly established mercury criteria for the state of Idaho, 2) to assist in identifying the primary source of mercury, areas of methylation, and 3) determine if there is a correlation between total mercury (THg)/ methylmercury (MeHg) levels in fish as related to levels found in the stream sediment and/or water column.

Four fish groups were targeted as being desirably species to achieve the objectives: adult red band trout, adult suckers, sculpin and young of the year (YOY) red band trout. Unfortunately, not all fish target groups were collected as planned. At the two lower stations near the Idaho-Oregon state line no large fish were captured. These large fish were to represent the catchable-edible criteria outlined in the Jordan Creek Mercury Evaluation study (Ingham 2005). At some other stations YOY trout and/or sculpins were not found. These smaller non-catchable-edible fish were targeted as the representative group in identifying possible sources of mercury and methylmercury.

Fish tissue samples were collected in June 2005 at five Jordan Creek sites and three non-Jordan Creek sites (Figure 1). Numerous species were collected, including those determined to be representative of the catchable-edible criteria. Other specices included suckers, dace, northern pick minnow, sculpin and YOY red band trout.. These samples represented tissue collected in the watershed where historic mining could have had an impact on water quality, and at other sites where there was no historic mining activity.

For each site, adult fish were composited by random combinations of individual fish, with each composite consisting of 3 or 4 fish. Young of the year red band trout, sculpin and other non-game smaller fish were taken as whole body samples and composited. All fish were processed in a clean laboratory following Environmental Protection Agency (EPA) clean hands-dirty hands protocols (EPA Method 1669). A total of 56 samples were obtained for the entire monitoring event (Appendix B).

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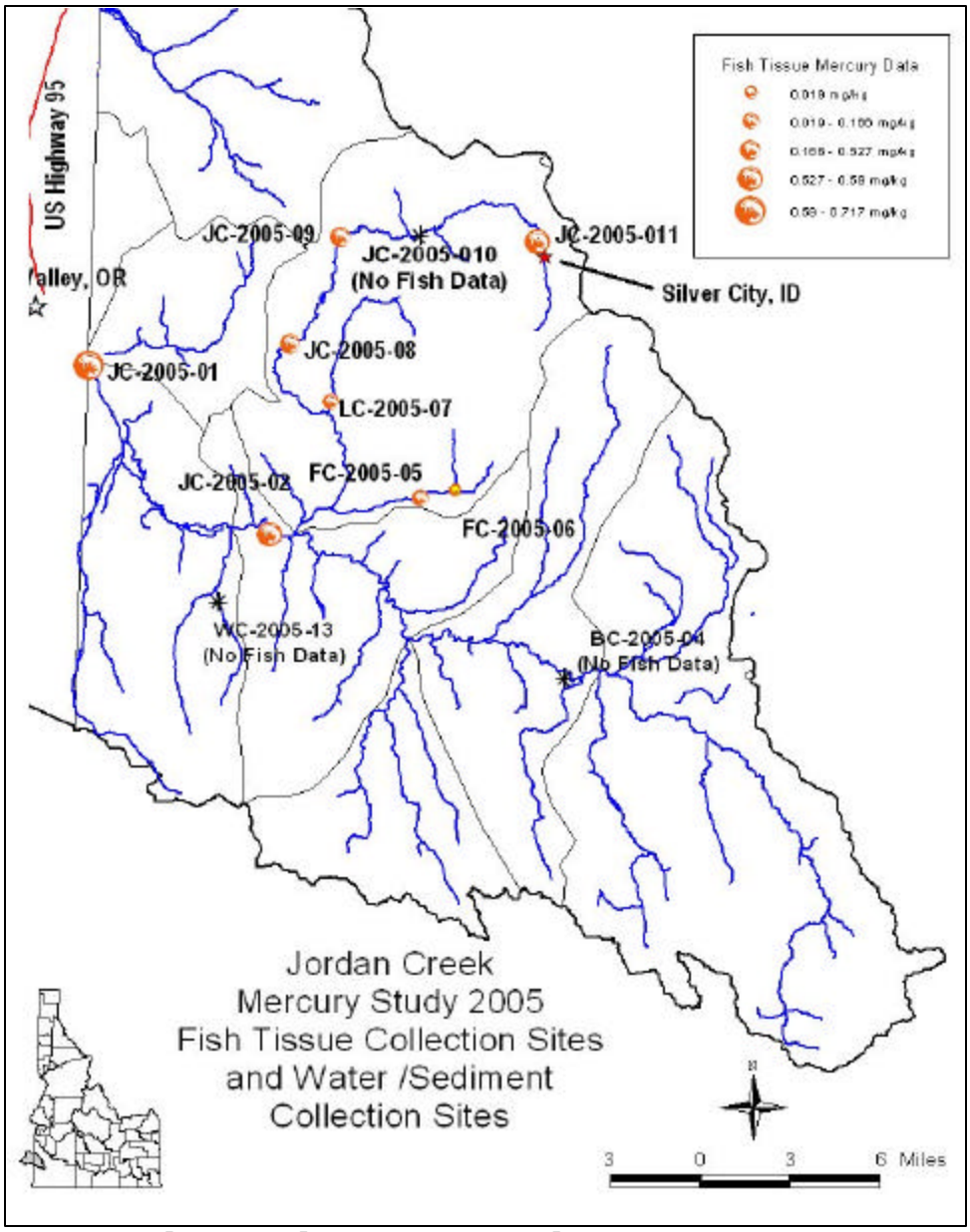

Figure 1. 2005 Jordan Creek Mercury Study.

Objectives of Data Analysis

Based on the laboratory data, this paper reports statistical analysis results to fulfill the following objectives:

1) to summarize statistics on fish total mercury concentrations (mg/kg) for each site (Figure 1);
2) to statistically test the difference in fish mercury concentrations in 1973 and in 2005;
3) to estimate total mercury levels in red band trout and suckers for Jordan Creek sites JC-2005-01 and JC-2005-02 (Ingham 2005).

Summary of Findings

We concluded from the analyses that:

1) Data from 2005 showed total mercury concentrations in Jordan Creek fish are significantly higher than those in the non-Jordan Creek fish. The average fish total mercury in Jordan Creek sites is 0.56 mg/kg with a 95% confidence interval (CI) of 0.51 and 0.61 mg/kg. For the three non-Jordan Creek sites, the average fish total mercury is 0.13 mg/kg and the 95% CI is 0.08 and 0.18.

2) There were fewer YOY fish in Jordan Creeks than in non-Jordan Creeks. Young of the year red band trout were found at only one Jordan Creek site (JC-2005-11). Total mercury in this whole body sample was 0.49 mg/kg. At the non-Jordan Creek sites the average total mercury concentration of seven YOY whole body composites was 0.03 mg/kg with a 95% CI of 0.02 and 0.04.

3) Total mercury concentrations in 2005 red band trout at Jordan Creek sites were significantly higher than in 1973 ($p < 0.001$) (Hill et al. 1973). However, no statistical difference was found in the fish mercury level between 2005 and 1973 for the non-Jordan Creek sites ($p = 0.60$). This analysis also showed variability in the 2005 composite red band trout samples were significantly lower than in the 1973 individual fish samples ($p < 0.01$). Compositing reduced the data variability by more than three times. This means, in order to achieve the same precision for the average fish mercury level in Jordan Creeks, compositing reduced the sample size requirement by nine times. Therefore, if a generic estimate (such as the mean fish mercury level) is of interest, compositing is recommended to obtain a more precise estimate and to reduce laboratory analytical costs.

4) Total mercury concentrations in Jordan Creek red band trout are predictable, provided the methylmercury concentrations of the water and the sediments are known. Fish weights-lengths are also good predictors for mercury levels in Jordan Creeks. In the non-Jordan Creeks sites, fish sizes do not influence fish mercury levels significantly. Table 1 summarizes the estimated mean red band trout total mercury concentration using the three predictors. The 95% CI for each estimate is also included.

Table 1. Predicted Total Mercury Concentrations (mg/kg) in Jordan Creek Red Band Trout, 2005.

			JC-2005-01		JC-2005-02	
Predictor	R_{Adj}^2	***n***	***Mean***	***(95% CI)***	***Mean***	***(95% CI)***
Sediment MeHg (mg/l)	0.94	5	0.75	(0.61,0.90)	0.67	(0.54,0.80)
Water MeHg (mg/l)	0.51	7	0.73	(0.46,1.2)	0.70	(0.44,1.1)
Composite weight (g)	0.79	6	0.54	(0.38,0.75)	0.60	(0.45,0.79)

The above predictions are for red band trout of typical length of 11.3 inches in Jordan Creek site JC-2005-01 and 6.8 inches in site JC-2005-02. The sizes are the averages from the observed red band trout in 1973. All three models showed that total mercury concentrations at the two sites

were greater than the 0.3 mg/kg fish consumption index (FCI). For this study, sediment methylmercury appeared to be the best predictor of red band trout mercury concentrations in Jordan Creek sites as indicated by a high R^2 and narrow confidence intervals.

5) No statistical difference was found for the total mercury concentrations in Jordan Creek suckers. Using the observations from the 1973 study, the average mercury level in suckers was 0.82 mg/kg with 95% CI of 0.71 and 0.94, for JC-2005-01 and 0.74 mg/kg with 95% CI of 0.63 and 0.85 for JC-2005-02. Typical sucker lengths at the two sites were 9.4 inches and 5.8 inches, respectively.

Objective 1: Summary Statistics on Fish Total Mercury Concentrations by Site

Figure 2 is the boxplot of total mercury concentrations in fish in 2005 by site. The box encloses the center 50% of the data (25% quantile to 75% quantile). The bar in the box is the median (50% quantile) of the data and the star is the average value of the data. Whiskers are 1.5 times the interquantile range (IQR) which is the 75% quantile - 25% quantile from the upper and lower sides of the box. Any observation beyond the whiskers is an extreme event in the data set.

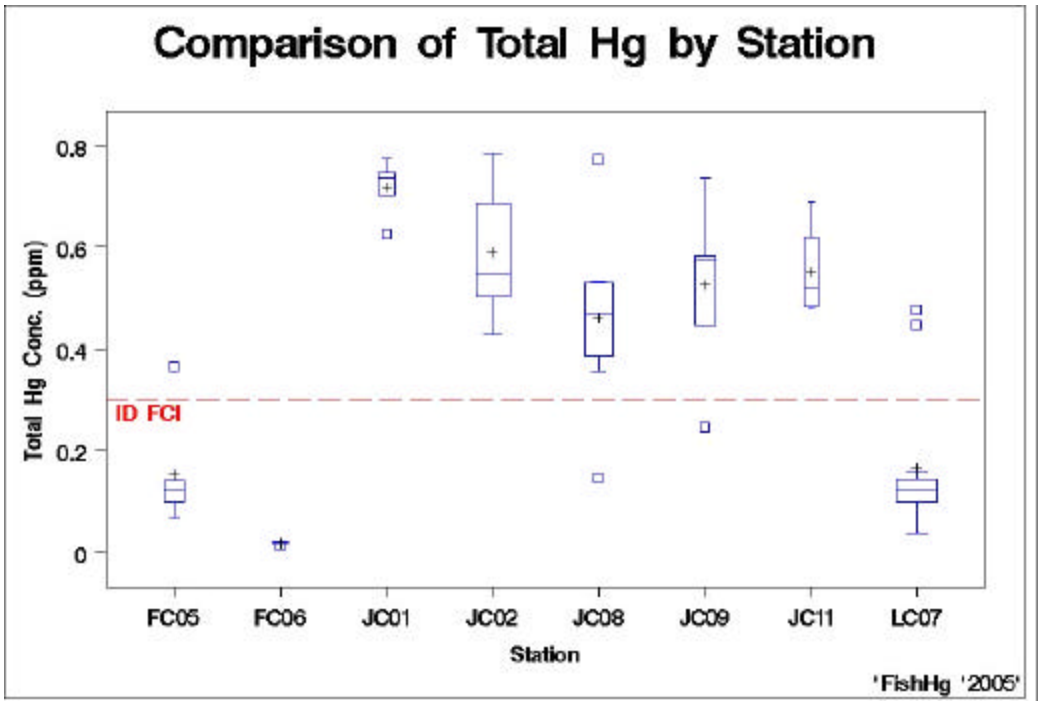

Figure 2. Comparison of Total Mercury Concentrations for all Species, 2005.

The dotted line in Figure 2 denotes the FCI for the State of Idaho, which is 0.3 mg/kg. Total mercury concentrations in fish from all Jordan Creek sites were above the FCI. For all sampled species, the average fish mercury level in Jordan Creeks in 2005 was 0.56 mg/kg with a 95% CI of 0.51 and 0.61. The highest observed fish mercury level was 0.72 mg/kg from JC-2005-01. However, no red band trout were caught at this site. Instead, the fish samples were mostly composite samples of dace, suckers, northern pike minnows and shiners. The lowest observed

Jordan Creek fish mercury concentration was 0.25 mg/kg from a red band trout composite sample at Jordan Creek site JC-2005-09.

For non-Jordan Creek total mercury levels in fish were less than the FCI. Out of the 18 red band trout and suckers samples from the three non-Jordan Creek sites, 17 samples had total mercury lower than 0.15 mg/kg. Total mercury concentration in one red band trout sample from Flint Creek was 0.37 mg/kg. However, this sample consisted of a fillet from a trout that was 12 inches in length and weighed 227 grams. The average fish length and weight for the Flint Creek site was 6.5 inches and 55 grams. Very likely the trout was not a resident, but had migrated from lower segments.

Figure 3 is the boxplot of total mercury concentrations found in fish from the 1973 study (Hill et al. 1973). Generally, the same pattern of high mercury concentration in Jordan Creek fish and low mercury concentration in non-Jordan Creek fish was observed. However, comparing to Figure 2, two items are noted; First, the average fish mercury levels in Jordan Creek site JC-2005-08, site JC-2005-09, and site JC-2005-11 were lower in 1973. Secondly, the compositing process used in 2005 monitoring reduced the variation of the observed fish mercury levels remarkably. This is indicated by the different y-scale of the two figures and the range of the center 50% of the data. Compositing attenuated the variability caused by individual differences in fish and the influence from extreme fish samples with high or low mercury levels.

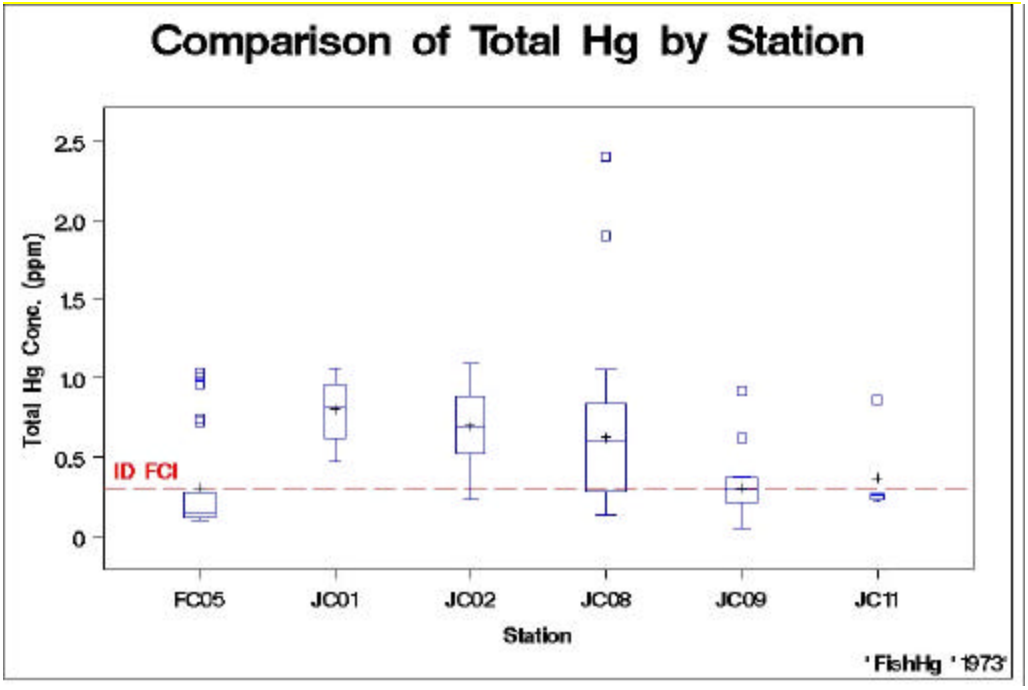

Figure 3. Comparison of Total Mercury Concentrations in all Species, 1973.

As red band trout and suckers are of primary interest, the box plots of these two species only, for 2005 and 1973, are shown in Figures 4 and 5. These plots show the general trend of red band trout and suckers mercury concentrations being high in Jordan Creek sites and low in non-Jordan Creek sites. Figures 3, 4 and 5 show that there were fewer red band trout and suckers samples in

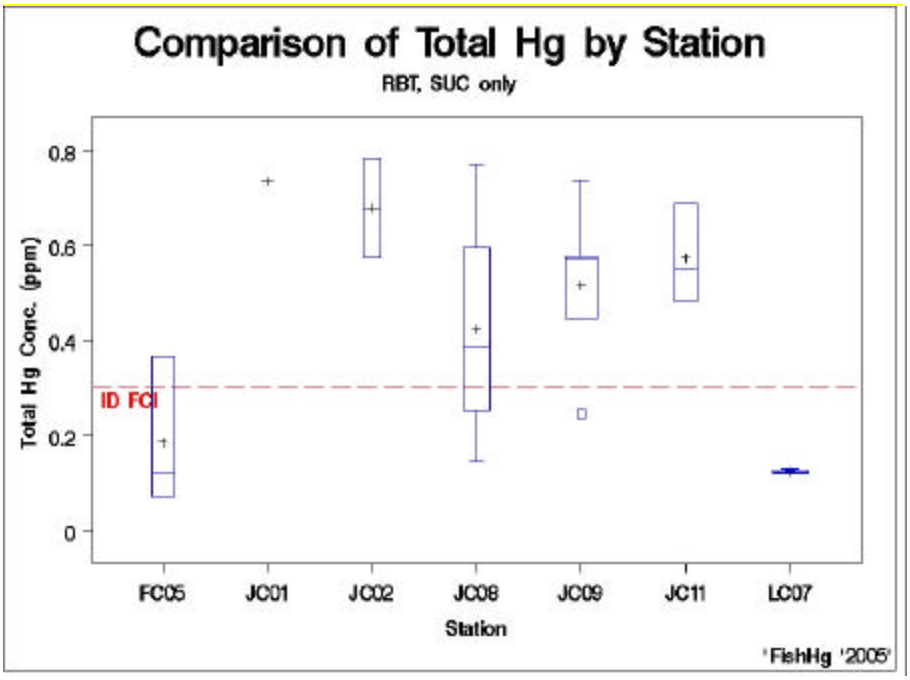

Figure 4. Box Plots of Total Mercury Concentrations in Red Band Trout and Suckers, 2005.

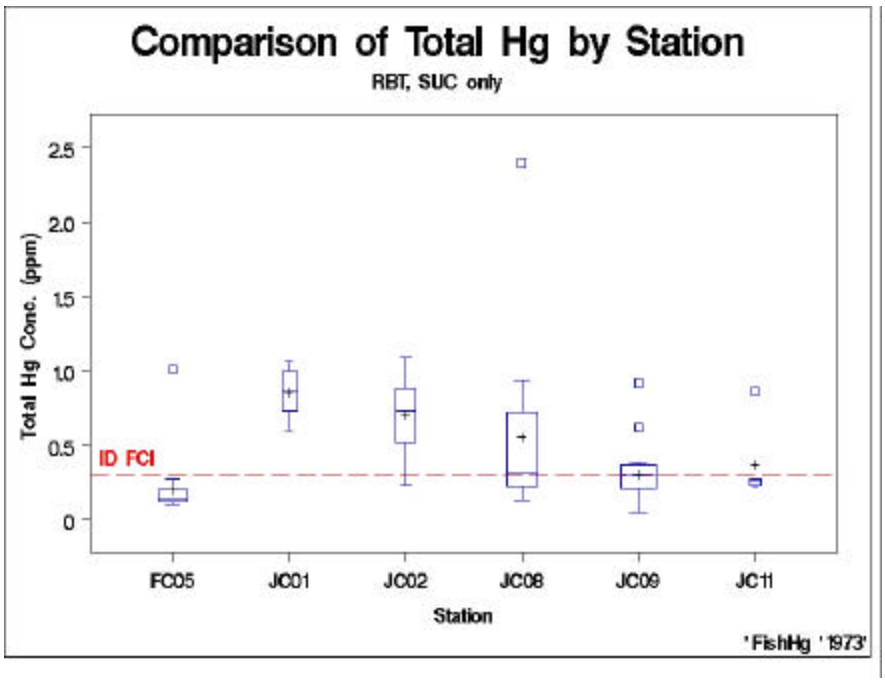

Figure 5. Box Plots of Total Mercury Concentrations in Red Band Trout and Suckers 1973.

Jordan Creek sites JC-2005-01 and JC-2005-02 as indicated by the narrowness of the boxes. In fact, no red band trout were found at these two sites, only suckers.

Objective 2: Results of statistical tests on the difference of total mercury concentrations in fish for 2005 and 1973

Two sample t-tests were used to compare total mercury concentrations in red band trout and suckers for the two time periods. Data were transformed using natural logarithm to meet the normality assumption of the test. The equal variance assumption was tested before applying the t-test. If an unequal variance was indicated, the t-test with unequal variance was applied. The F-test showed the equal variance assumption could not be used for comparisons at Jordan Creek sites ($p < 0.01$ for both red band trout and suckers). Compositing in 2005 reduced the variability of observed data. Therefore, the t-test with unequal variance was applied to compare red band trout and suckers mercury level at Jordan Creek sites. However, the equal variance assumption held for non-Jordan Creek site comparisons.

Table 2 summarizes the results of the t-test on the fish mercury concentrations in 1973 and in 2005. For Jordan Creek sites, significantly higher total mercury levels were found in 2005 red band trout than in 1973 ($p < 0.001$). For the non-Jordan Creek sites total mercury concentrations in red band trout did not differ significantly between 2005 and 1973. For suckers, no mercury level difference were found at Jordan Creek sites ($p = 0.30$). Comparison to total mercury concentrations in suckers for the non-Jordan Creek sites was not applicable due to the lack of samples.

Table 2. Summary of t-test results for total mercury concentrations in Jordan creek and non-Jordan creek red band trout and suckers in 1973 and 2005.

Hypothesis	*Red Band Trout*	*Suckers*
Jordan Creek		
H_0: $\ln(THg)_{1973} = \ln(THg)_{2005}$ H_A: $\ln(THg)_{1973} \neq \ln(THg)_{2005}$	p< 0.001 Therefore reject H0, there is a difference in Total Hg concentration in red band trout for 1973 and 2005 at significance level (α) of 0.05.	p=0.30 Therefore accept H0, there is no difference in Total Hg concentration in suckers for 1973 and 2005 at significance level (α) of 0.05.
Non-Jordan Creek		
H_0: $\ln(THg)_{1973} = \ln(THg)_{2005}$ H_A: $\ln(THg)_{1973} \neq \ln(THg)_{2005}$	p=0.60 Therefore accept H0, there is no difference in Total Hg concentration in red band trout for 1973 and 2005.	N/A. No suckers were sampled in LC-2005-07 for both years and no suckers were found in FC2005-05 in 2005.

Objective 3: Estimates of total mercury concentrations in red band trout and suckers of Jordan Creek site JC-2005-01 and JC-2005-02.

Both sites, JC-2005-01 and JC-2005-02, did not produce catchable-edible size fish during the electrical fishing effort in June 2005. However, it is desirable to know the mercury concentrations in red band trout and suckers at these locations. Therefore, various prediction models were tested using mercury levels in the stream sediments, the water column and fish.. Methylmercury in sediment (Model 1), methylmercury in water (Model 2), and composite fish weight (Model 3) were found to be good predictors. For each predictor, a model was developed. Residual plot and residual Q-Q plot were examined for adequacy of the model and normality assumptions. The adequacy and assumptions were satisfied for each developed model. The models and the goodness of fit (R_{adj}^2) for each are listed in Table 3. Observations (dots) and fitted models (lines) are shown in Figures 6, 7 and 8.

Table 3. Summary of Prediction Models for Red Band Trout, Total Mercury Concentrations for Jordan Creek Site JC-2005-01 and Site JC-2005-02.

Predictor	***Model #***	***Model***	R_{adj}^2
Sediment MeHg (mg/l)	1	$THg_{RBT} = 0.52 + 0.095 \ln(MeHg)_{sedi}$	0.94
Water MeHg (mg/l)	2	$\ln(THg)_{RBT} = -0.67 + 0.41 \ln(MeHg)_{H_2O}$ ***OR*** $THg_{RBT} = 0.51 e^{0.41}$	0.51
Composite weight (g)	3	$\ln(THg) = -2.74 + 3.34 \ln(\ln(weight - 40)) - 1.23(\ln(\ln(weight - 40)))^2$	0.79

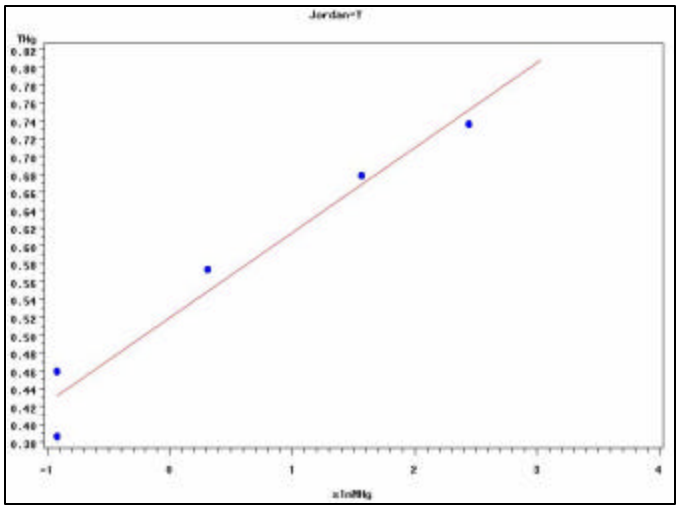

Figure 6. Observed vs. Predicted Red Band Trout, Total Mercury Concentrations Using Model #1

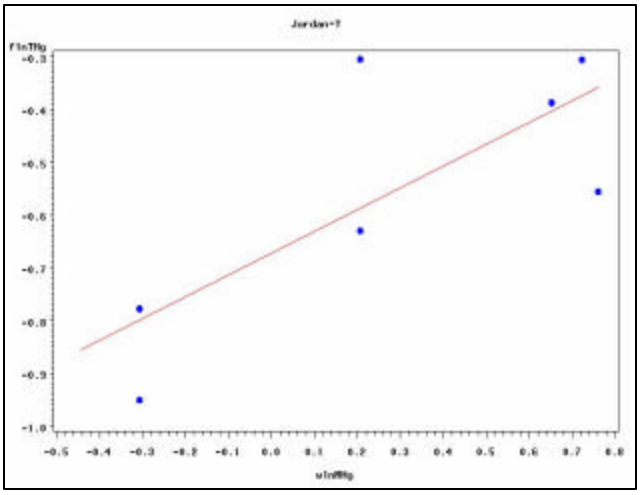

Figure 7. Observed vs. Predicted Red Band Trout, Total Mercury Concentrations Using Model #2

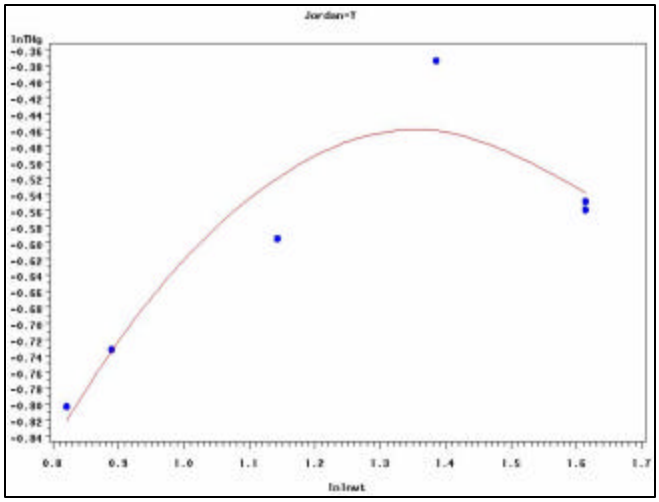

Figure 8. Observed vs. Predicted Red Band Trout, Total Mercury Concentrations Using Model #3

Table 4 summarizes the predicted mean red band trout mercury levels with a 95% CI using the chosen models. The weight model (Model 3) is good for red band trout heavier than 40 grams. This is equivalent to red band trout of approximately 5.8 inches long. The weight-length relationship was developed using the 2005 monitoring data. Red band trout length and weight are predictable by each other by using the power function:

$$fishweight = 0.164\ (length\ )^{3.12}$$

Where: fish weight is in grams and fish length is in inches

The model's R^2 is 0.91, indicating good model fit. Extrapolation of the weight model (Model 3) for younger fish should be done cautiously. The summary of fish sizes in the 1973 study for the 2005 monitoring sites can be found in the appendix.

Table 4. Predicted Mean Total Mercury Concentrations in Red Band Trout in Jordan Creek Site JC-2005-01 and Site JC-2005-02.

	JC-2005-01			***JC-2005-02***		
	Model 1	***Model 2***	***Model 3***	***Model 1***	***Model 2***	***Model 3***
Mean	0.75	0.73	0.54	0.67	0.70	0.60
Lower 95% limit	0.61	0.46	0.38	0.54	0.44	0.45
Upper 95% limit	0.90	1.2	0.75	0.80	1.1	0.79

Since no statistical difference was found for the sucker's mercury levels at Jordan Creek sites, suckers total mercury concentrations for JC-2005-01 and JC-2005-02 were estimated from observations in 1973. The estimated average suckers mercury level for the two sites were 0.82 mg/kg with a 95% CI of 0.71 and 0.94 for site JC-2005-01, and 0.74 mg/kg with a 95% CI of 0.63 and 0.85 for site JC-2005-02.

References

Hill, Steve, A. Cochrane and D. Williams 1973. Study of mercury and heavy metals pollutants in the Jordan Creek drainage. University of Idaho, College of Mines, Moscow, ID.

Ingham, Michael, J. 2005, Jordan Creek Mercury Evaluation Quality Assurance Project Plan. Idaho Department of Environmental Quality. Boise, ID

Appendix: Data

Table A. Average Fish Lengths of Species Found in 1973 Silver City Study (Hill et al. 1973).

Station	*Species*	*N*	*Mean Length (inches)*	*Median Length (inches)*	*StdDev Length (inches)*
FC-2005-05	RBT	14	6.0	6.0	1.2
FC-2005-05	SCP	5	2.0	2.0	0.0
FC-2005-05	SUC	6	6.8	6.5	1.0
JC-2005-01	RBT	3	11.3	11.5	1.3
JC-2005-01	RSS	4	2.3	2.0	0.5
JC-2005-01	SUC	7	9.4	10.0	2.2
JC-2005-01	SWF	2	7.5	7.5	0.7
JC-2005-02	PMC	1	6.5	6.5	
JC-2005-02	RBT	6	6.8	6.5	1.0
JC-2005-02	RSS	3	3.5	3.0	0.9
JC-2005-02	SCP	2	2.0	2.0	0.0
JC-2005-02	SUC	12	5.8	5.8	1.6
JC-2005-02	SWF	3	6.5	7.0	0.9
JC-2005-08	DAC	3	2.7	3.0	0.6
JC-2005-08	RBT	14	8.5	8.0	2.8
JC-2005-08	RSS	3	3.5	4.0	1.3
JC-2005-08	SUC	9	8.6	9.0	1.9
JC-2005-08	SWF	5	8.4	8.0	1.7
JC-2005-09	RBT	28	5.2	5.0	1.7
JC-2005-09	SUC	1	4.0	4.0	
JC-2005-11	RBT	9	5.4	5.0	1.0

Table B. 2005 Results; Fish Tissue, Sediment and Water Column for 2005.

Station	Site Description	Date Field	Time Field	Sediments Total Hg Dry (ng/g)	Sediments MeHg Dry (ng/g)	Water MeHg (ng/l)	Water Total Hg (ng/l)	Water Diss Hg (ng/l)	Average Fish Total Hg (mg/kg)
JC-2005-01	Jordan near Stateline	8/8/2005	11:30	4260.439	11.520	2.060	19.944	9.166	0.717
JC-2005-02	Jordan Below Boulder Cr.	8/10/2005	15:30	2046.348	4.797	1.920	31.407	13.332	0.590
JC-2005-08	Jordan Below Placier Tailings	8/9/2005	11:00	1292.407	0.399	0.736	13.347	5.226	0.461
JC-2005-09	Jordan Below Delamar Mine	8/8/2005	18:00	1348.770	31.918	1.230	35.270	19.547	0.527
JC-2005-11	Jordan Below Silver City	8/9/2005	9:00	947.547	1.366	2.140	92.680	89.460	0.551
Background Stations									
BC-2005-04	Boulder Creek	8/9/2005	16:30	9.739	31.025[a]	0.2360	1.240	1.979	NA
FC-2005-05	Flint Creek	8/9/2005	14:00	13.822	0.985	0.2770	1.219	0.839	0.154
FC-2005-06	East Fork	8/9/2005	15:30	3.192	0.303	0.0520	0.763	0.500	0.188
WC-2005-13	Williams Creek	8/8/2005	12:30	5.241	0.029	0.2140	1.804	1.065	NA
LC-2005-07	Louse Creek	8/8/2005	15:30	16.442	0.231	0.103	1.397	0.779	0.166

a Data review is being conducted by Brooks Rand to determine why this result would be incorrect. It is impossible to have MeHg result exceeding the Total Hg result for a single sample. One explanation provided to date is the division of the sample which contained high amounts of organic material (algae, roots…) which may affect the aliquoting of the sample.

Table C. Individual Fish Tissue Results 2005.

Type	Species	Station ID	Sample ID	RESULT	UNIT
WB-COMP	DAC	JC-2005-01	05264152	0.77460317	mg/kg-wet
WB-COMP	NPM	JC-2005-01	05264158	0.70250209	mg/kg-wet
WB-COMP	RSS	JC-2005-01	05264161	0.6258159	mg/kg-wet
WB-COMP	SUC	JC-2005-01	05264178	0.73633333	mg/kg-wet
WB-COMP	CMS	JC-2005-01	05264164	0.74734188	mg/kg-wet
				0.71731928	
WB-COMP	SUC	JC-2005-02	05264150	0.78376812	mg/kg-wet
WB-COMP	RSS	JC-2005-02	05264182	0.52570175	mg/kg-wet
WB-COMP	CMS	JC-2005-02	05264185	0.50242672	mg/kg-wet
WB-COMP	DAC	JC-2005-02	05264188	0.68740376	mg/kg-wet
WB-COMP	NPM	JC-2005-02	05264191	0.77678995	mg/kg-wet
WB-COMP	SUC	JC-2005-02	05264194	0.57366667	mg/kg-wet
WB-COMP	LND	JC-2005-02	05264197	0.42863877	mg/kg-wet
WB-COMP	RSS	JC-2005-02	05264199	0.52487773	mg/kg-wet
WB-COMP	BLS	JC-2005-02	05264200	0.60475799	mg/kg-wet
WB-COMP	SCP	JC-2005-02	05264202	0.48834188	mg/kg-wet
				0.58963733	
WB-COMP	DAC	JC-2005-08	05264166	0.49960177	mg/kg-wet
WB-COMP	DAC	JC-2005-08	05264166	0.53177778	mg/kg-wet
WB-COMP	DAC	JC-2005-08	05264166		%Rec
WB-COMP	DAC	JC-2005-08	05264166		%Rec
COMP-IND	RBT	JC-2005-08	05264157	0.35558685	mg/kg-wet
COMP-IND	RBT	JC-2005-08	05264160	0.41734234	mg/kg-wet
WB-COMP	NPM	JC-2005-08	05264169	0.43699592	mg/kg-wet
WB-COMP	SUC	JC-2005-08	05264172	0.77241126	mg/kg-wet
COMP-IND	SUC	JC-2005-08	05264163	0.14632212	mg/kg-wet
WB-COMP	RSS	JC-2005-08	05264175	0.53129752	mg/kg-wet
				0.46141694	
WB-COMP	DAC	JC-2005-09	05264154	0.58184956	mg/kg-wet
COMP-IND	RBT	JC-2005-09	05264168	0.24579646	mg/kg-wet
COMP-IND	RBT	JC-2005-09	05264171	0.57773423	mg/kg-wet
COMP-IND	RBT	JC-2005-09	05264174	0.57173516	mg/kg-wet
COMP-IND	RBT	JC-2005-09	05264177	0.44794118	mg/kg-wet
COMP-IND	SUC	JC-2005-09	05264151	0.73688073	mg/kg-wet
				0.52698955	
COMP-IND	RBT	JC-2005-11	05264153	0.55165939	mg/kg-wet
COMP-IND	RBT	JC-2005-11	05264156	0.48072414	mg/kg-wet
COMP-IND	RBT	JC-2005-11	05264159	0.68798701	mg/kg-wet
WB-COMP	RBT-YOY	JC-2005-11	05264162	0.48516129	mg/kg-wet
				0.55138296	

Table C (cont.). Individual Fish Tissue Results 2005.

Type	Species	Station ID	SAMPLE ID	RESULT	UNIT
WB-COMP	SCP	FC-2005-05	05264167	0.142318182	mg/kg-wet
COMP-IND	RBT	FC-2005-05	05264176	0.365535714	mg/kg-wet
COMP-IND	RBT	FC-2005-05	05264179	0.122133333	mg/kg-wet
COMP-IND	RBT	FC-2005-05	05264180	0.070442478	mg/kg-wet
WB-COMP	RBT	FC-2005-05	05264183	0.099286364	mg/kg-wet
WB-COMP	SCP	FC-2005-05	05264170	0.125591837	mg/kg-wet
				0.154217985	
WB-COMP	RBT-YOY	FC-2005-06	05264184	0.021702439	mg/kg-wet
WB-COMP	RBT-YOY	FC-2005-06	05264190	0.0125	mg/kg-wet
COMP-IND	RBT-YOY	FC-2005-06	05264192	0.022143564	mg/kg-wet
COMP-IND	RBT-YOY	FC-2005-06	05264195	0.019476389	mg/kg-wet
COMP-IND	RBT-YOY	FC-2005-06	05264198	0.018275674	mg/kg-wet
				0.018819613	
COMP-IND	RBT	LC-2005-07	05264203	0.126427966	mg/kg-wet
WB-COMP	RBT	LC-2005-07	05264214	0.130282297	mg/kg-wet
COMP-IND	RBT	LC-2005-07	05264205	0.118832653	mg/kg-wet
COMP-IND	RBT	LC-2005-07	05264209	0.121423077	mg/kg-wet
COMP-IND	RBT	LC-2005-07	05264209	0.119375664	mg/kg-wet
WB-COMP	BLS	LC-2005-07	05264206	0.079201681	mg/kg-wet
COMP-IND	Sucker	LC-2005-07	05264207	0.124696356	mg/kg-wet
WB-COMP	RSS	LC-2005-07	05264210	0.159526749	mg/kg-wet
COMP-IND	LND	LC-2005-07	05264211	0.47764878	mg/kg-wet
WB-COMP	SCP-Short Head	LC-2005-07	05264212	0.44735545	mg/kg-wet
WB-COMP	RBT-YOY+1	LC-2005-07	05264204	0.038115385	mg/kg-wet
WB-COMP	RBT-YOY+1	LC-2005-07	05264204	0.046531532	mg/kg-wet
				0.165784799	